REQUIREMENTS OF A TELEVISION SYSTEM

55RH-2

NATIONAL RADIO INSTITUTE
ESTABLISHED 1914
WASHINGTON, D. C.

PIONEER HOME STUDY RADIO SCHOOL
NRI

STUDY SCHEDULE

For each study step, read the assigned pages first at your usual speed, then reread slowly one or more times. Finish with one quick reading to fix the important facts firmly in your mind. Study each other step in this same way.

☐ 1. Basic Principles of Television .... Pages 1 - 3

The uses and limitations of television signals and the basic equipment used to transmit and receive these signals are given.

☐ 2. Image Scanning in Television .... Pages 3 - 8

How, in a sequence of pictures, each is broken down into elemental impressions, and how these impressions and necessary synchronizing signals are transmitted.

☐ 3. The Cathode Ray Tube as an Image Reproducer .... Pages 8-14

How a cathode ray tube in the television receiver can be used to reassemble the elemental impressions to reproduce the television signal.

☐ 4. How Interlaced Scanning Reduces Flicker .... Pages 14-16

How 60 pictures per second are used to reduce flicker within the band width requirements of a 30-picture-per-second system.

☐ 5. Brightness and Contrast Controls .... Pages 17-19

The principles of operation and adjustment of these two important controls in television systems are considered.

☐ 6. Television Signal Standards .... Pages 19-24

The technical standards of television signals and synchronizing pulses which affect both transmitter and receiver operation.

☐ 7. Television Receiver Circuits and Controls .... Pages 24-28

The basic circuits in the usual type of the two-i.f.-channel superheterodyne television receivers are given.

☐ 8. Answer the Lesson Questions and Mail Your Answers to NRI for Grading.

☐ 9. Start Studying the Next Lesson.

NPC6M249 1949 Edition Printed in U.S.A.

REQUIREMENTS OF A TELEVISION SYSTEM

Basic Principles of Television

With this Lesson you begin your special training in the field of television. This first Lesson will give you a comprehensive picture of a complete modern television system, showing how it is possible to see on the screen of a cathode ray tube in a receiver a scene which is at that same instant being viewed by the television camera many miles away in a studio.

In the NRI television Lessons you will find presented in a simple, logical, and understandable manner the important principles underlying all phases of modern cathode ray television systems. After mastering these Lessons, you will find it remarkably easy to keep in step with new developments in this exciting and rapidly growing field.

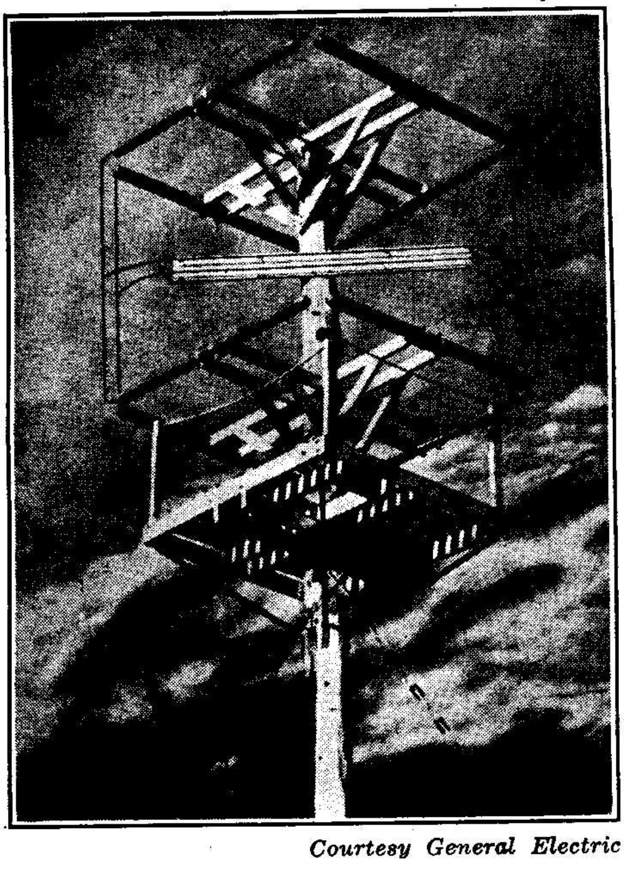
THE process of scanning which breaks up a televised scene into successive signal elements results in a frequency range for picture signals of from nearly zero to more than

Courtesy Philco Radio & Television Corp.

The quality of the picture produced by a modern television receiver is evident in this image produced on the screen of a Philco television receiver (showing Mr. Larry E. Gubb, president of Philco Radio & Television Corp.). The actual image as viewed on the screen is much clearer, for considerable detail is lost in photographing the image and in reproducing the photo as a half-tone cut.

4,000,000 cycles (4 megacycles, abbreviated 4 mc.) per second. Radio waves constitute a logical carrier for bringing these picture (video) signals to a large number of people at any one time, but only very-high-frequency carriers are suitable for carrying through space a signal which has a frequency range of over 4 mc.

Very - high - frequency signals are bent only slightly by moisture in the air, and are not satisfactorily reflected by the Kennelly-Heaviside sky layer; this means that reliable television reception is generally limited to points that can be reached by signals traveling in straight lines from the transmitter. With receiving and transmitting antennas at practical heights, the maximum range of reliable reception from a given transmitter is about 50 miles. The transmission of television signals over radio carriers is therefore essentially a local service. Each community must have its own local transmitting station, serving television receivers within a radius of about 50 miles. These local stations can be connected to one another and to a central source of television programs either by special coaxial cable or by microwave radio relay transmitters when national coverage is to be secured for a particular program.



Courtesy General Electric

Cubical transmitting antenna of General Electric 10-kw. television station W2XB, located in the Helderberg hills 12 miles outside of Albany, N. Y. The antenna consists of eight hollow copper tubes each four inches in diameter and about seven feet (one-half wavelength) long, arranged to form a perfect cube which will radiate horizontally polarized waves for both picture and voice carriers in the 66-72 mc. television channel. Being atop a 1500-foot hill, good coverage is expected for distances of 40 miles in all directions.

Television must be accompanied by sound in order to be fully appreciated, just as everyone today expects movies to be accompanied by sound. Plans for television assume that sight and sound are transmitted simultaneously. Television will in no sense replace sound broadcasting; the reception of sound programs by radio will continue to expand as it has in the past, and television will simply be an added service to listeners for some time to come.

TELEVISION IS AN EXTENSION OF RADIO PRINCIPLES

A television camera is needed to pick up picture signals in a television studio, and a special reproducing device is required at the receiver to reproduce the transmitted picture; between these two special devices, however, we find a great many familiar radio circuits. At the television transmitter there is a master oscillator which generates the very-high-frequency carrier, together with r.f. power amplifiers, a modulator, linear r.f. power amplifiers and a transmitting antenna. At the receiving location the television signals are picked up by an antenna, and are amplified and selected in the preselector of the

television receiver. This receiver, if of the superheterodyne type, will have a local oscillator, a mixer-first detector, an i.f. amplifier, a demodulator, and a picture-signal amplifier, all of which prepare the received signal for the picture-producing device. The sound accompaniment for a television program is handled in essentially the same way as in f.m. program broadcasting except that the frequency deviation is limited to ± 25 kc.

Television equipment has its full complement of tubes, coils, resistors, condensers, transformers, and wires, just as ordinary sound radio equipment does. Television circuits may be identical with radio circuits, or they may be entirely new circuits developed to meet the special requirements of picture transmission and reception.

Sounds, no matter how complex, are inherently a succession of signal intensities. Unfortunately, a scene does not exist in this desired state; *a scene must therefore be converted into a succession of signal intensities by a process of scanning,* as the first step in sending images by radio or wire. The television camera provides this scanning, and feeds into the television system a signal corresponding to that fed into a radio system by a microphone. The succession of signal intensities in a television signal is handled by the transmitting and receiving systems in a more or less conventional manner. These varying intensities must be reassembled in proper sequence and position by an image-reproducing device at the output of the receiver in order to reconstruct the original scene. The image reproducer in a television system corresponds to the loudspeaker in a sound receiver.

To insure proper step-by-step reconstruction of the scene at the receiver, the circuit which controls the scanning at the television camera must also control the image-reconstructing process at the receiver; this control is referred to as *synchronization.* The synchronizing signals are produced by unique oscillator circuits, are sent out on the carrier along with the picture signals in a more or less conventional manner, and are separated from these signals at the receiver by special circuits which do not exist in the usual sound receiver. In the final analysis, however, all of these special circuits are based upon extensions of well-known electrical and radio principles.

Once the requirements of a television system are recognized, the special circuits in television transmitters and receivers will seem quite natural and obvious rather than something strange and new. By studying the process of scanning first, giving special emphasis to the synchronizing signals and the circuits which handle these signals, we can make television circuits seem just as logical and understandable as ordinary radio circuits. This Lesson is primarily intended to get you acquainted with the important problems in television.

Image Scanning in Television

When we look at a picture or scene, we see various colors and various shades in each color, arranged side by side or blended together according to the nature of the scene. An ordinary photograph, on the other hand, appears to be in various shades of one color. If we were to examine a photo-

FIG. 1A. A perfect printed reproduction of a line drawing, made by means of a zinc "cut."

FIG. 1B. Line drawing reproduced as dots of various sizes, with 60 dots per inch.

graph under a strong magnifying glass or microscope, however, we would see countless small dots, each a different shade of gray ranging from white to black; each dot is one grain in the photo-sensitive emulsion on the surface of the photograph. This is mentioned merely to show that all photographs, whether in black and white or in natural colors, have a grain or a dot formation which is so small that it normally blends together like a natural scene and is invisible to the naked eye. For practical television purposes we can consider a photograph as being equivalent to an actual scene.

There is as yet no printing process which will give perfect reproduction of a photograph which contains many shades of gray or another color blended together. It is necessary for the engraver to break up the photograph into a series of dot impressions, then make a "cut" or "plate" which will print these dots. Careful examination of any photographic reproduction in a newspaper, magazine, or book will reveal these dots to you; it may be necessary to use a magnifying glass in some cases, for the dots are very small in high-quality printing on a smooth, glossy paper. Note that in the darker or black areas the dots are largest, and that they become smaller and smaller as you examine increasingly light shades of gray.

A line drawing like that in Fig. 1A can be reproduced accurately by a printer without being broken up into large and small dots, and consequently we can use this drawing as an example and show how it appears originally and when broken up into various numbers of dots or lines. If we break up this drawing into 60 dots per inch in each direction, and make the size of each dot correspond to the average darkness over its corresponding 1/60th-inch square area in Fig. 1A, we secure the half-tone reproduction shown in Fig. 1B. The dots are arranged horizontally and vertically here for purposes of illustration, but in the usual photographic reproduction they are run diagonally so the screen pattern will not be so noticeable to the eye.

The dots in Fig. 1B are clearly visible at a normal reading distance, but if you hold this illustration about four feet away from your eyes, the dots will blend together to give the impression of a picture composed only of gray and black areas. Increasing the number of dots in a given area has the same effect as holding the illustration at a distance. Figure 2A has twice as many dots per inch on any one line as has Fig. 1B. Note that these dots blend together at a distance of about 2 feet from your eyes. The more dots there are per square inch in a photographic repro-

FIG. 2A. Line drawing reproduced as dots of various sizes, with 120 dots per inch both horizontally and vertically.

FIG. 2B. Line drawing reproduced as horizontal lines of varying thickness, with 120 lines per inch.

duction, the better is the quality of reproduction. A large number of dots gives what is known in television as "high definition."

Lines of varying widths may be used in place of dots for photographic reproductions; an example of this is shown in Fig. 2B. The method of image reproduction used in television is essentially the same as this, except that in television the lines are of constant width and vary in intensity of illumination. There are 120 lines per inch in Fig. 2B, and there may be even more than 120 variations in line thickness for each inch of line length. Obviously, it is possible to get high definition with lines as well as with dot patterns. This is an important factor in the reproduction of television images.

When reproducing pictures by the process of printing, there are no real difficulties involved in securing as many as 200 dots per inch on a line, giving what is commonly referred to as a 200-line screen. In television, however, there is a limit to the amount of detail or definition which can be secured without exceeding the practical limits of the equipment. The number of dot elements per line, and the number of lines per picture are definitely limited in television by the maximum frequency range which can be handled by the system.

The *larger* the image size produced by the television receiver, the *farther away* the viewers must be if they are to see a properly blended picture rather than an assemblage of lines and line variations. For example, if we enlarged Fig. 1B to twice its size, giving 3600 dots in a 2-inch square illustration as shown in Fig. 3, we would find it necessary to move twice as far away (to a distance of about 8 feet) in order for the dots to blend together.

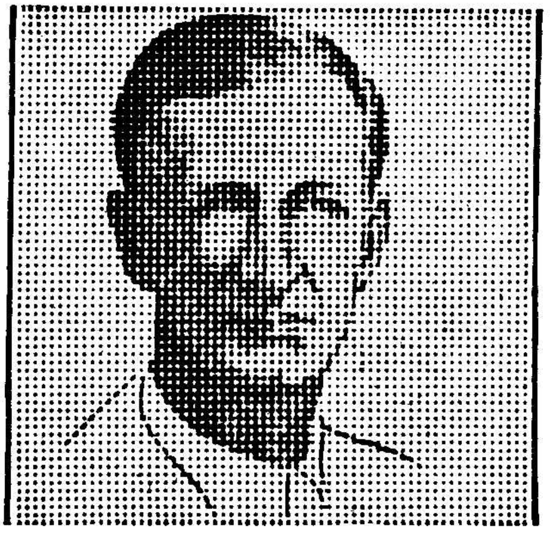


FIG. 3. When Fig. 1B is enlarged to twice its size, we get this result. There are now 30 dots per inch, but the total number of dots in the picture is the same as in Fig. 1B.

TRANSMISSION OF A SCENE

We have seen how a scene can be divided into elemental impressions which, when reproduced as a series of dots or variable-intensity lines, will show almost as much detail as the original scene. Now let us see how the line variations in Fig. 2B can be sent to a distant point in proper sequence, either over a wire or by means of a radio carrier signal.

Imagine a lens and photocell combination which can "see" only one small area of the picture in Fig. 1A at a time. (A photocell—often called an "electric eye"—is a device having a voltage output that depends on the amount of light falling on the cell.) Assume that this electric eye looks first at the upper left-hand corner of the picture, then moves gradually over to the upper right-hand corner, looking carefully at each elemental impression along this uppermost horizontal line of the picture. At the end of this line a mechanical force shifts the electric eye back to the left and down a little to the start of the second line. Assume that this "scanning" from left to right continues until the electric eye has looked

over the bottom line, at which time another mechanical force moves the electric eye back to its starting point at the upper left-hand corner. This action constitutes one complete scanning of the picture. The varying amounts of light reflected into the photocell by the elemental areas of the picture cause the voltage output of the cell to vary from instant to instant, and this varying picture signal voltage can be sent through space or over wires by a television system.

At the receiving end of our television system, let us imagine that we have a small nozzle which is spraying on paper a stream of ink which always covers the same definite area. This nozzle is designed so that the amount of ink which is delivered at any instant can be controlled electromagnetically; furthermore, the nozzle is so mounted that it will start spraying at the upper left-hand corner of the paper, and will travel horizontally to the right at a uniform speed corresponding as nearly as possible to the travel of the electric eye at the television scanner. The television signal which is picked up by the receiver is amplified and made to control the amount of ink flowing from the nozzle at any instant. A mechanical force returns the nozzle to the start of the second line at the same instant that the electric eye reaches the corresponding position on the original picture, and thus the nozzle delivers, for each elemental area of the paper at the receiver, an amount of ink proportional to the darkness of the corresponding elemental area on the picture. The result is that when the nozzle has completed the bottom line of the picture, it has painted with ink an almost exact reproduction of the picture at the transmitter. In a properly designed circuit, a low current would open the valve and deliver a large amount of ink; large currents would close the valve, reproducing the white portions of the original scene.

In this imaginary television system, it is essential that the electric eye and the ink nozzle start moving at exactly the same instant, travel at the same speed, and at the end of each line fly back to the start of the following line in synchronism with each other. This could, of course, be accomplished with automatic manual mechanisms, but there would be no assurance that the two devices would keep in step. Even if the nozzle happened to be only slightly slower or faster than the electric eye, there might be as much as half a line difference or error after a few lines. We therefore arrive at this conclusion: *The television transmitter must, at the end of each line, send a signal impulse which will serve to swing the reproducing device back to the start of the following line in synchronism with the television camera.* With this requirement met, we know that the transmitting and receiving devices will start each line at the same instant, even though they may vary in speed a certain amount during a given line. The impulse which is sent at the end of each line for reproducer-controlling purposes is called the *line synchronizing impulse* or the *horizontal synchronizing impulse.* In a practical transmitter this impulse is not produced by the electric eye, but rather by an impulse generator in the transmitter which directly controls the travel of the scanning eye and which by means of the connecting medium (wires or radio carriers), controls the travel of the reproducing device.

We must likewise provide means for returning the reproducing device from the lower right-hand corner to the upper left-hand corner at exactly

the same instant that the electric eye makes this movement. This means that the transmitter must send an end-of-the-picture impulse to the receiver along with the varying line signals and the end-of-the-line impulses. This end-of-the-picture impulse is called the *picture synchronizing impulse, the frame synchronizing impulse, or the vertical synchronizing impulse.*

The left-to-right scanning motion along a line is commonly called the *horizontal sweep.* The quick right-to-left return motion from the end of one line to the beginning of the next is called the *line fly-back, horizontal fly-back, or horizontal retrace.* The downward line-by-line movement from the top to the bottom of the picture is called the *frame sweep* or *vertical sweep.* The quick bottom-to-top motion is called the *frame fly-back, the vertical retrace,* or *the vertical fly-back.*

The mechanical picture-sending and receiving system just described corresponds to one practical scheme for picture or facsimile transmission (the sending of photographs from one point to another by wire or radio; also known as wire-photo). As you have just seen, the three important signals which must be transmitted on the picture carrier in an electronic television system are: 1. The *picture signal* or video signal, which is obtained by breaking up the picture into a number of elemental areas and scanning each of these in an orderly sequence; 2. The *line synchronizing impulses* or horizontal synchronizing impulses; 3. The *frame synchronizing impulses* or vertical synchronizing impulses.

Actual Television Transmission. During the transmission of a television signal, the line impulse exists for an instant after each line has been scanned, and the frame (picture) impulse exists for a longer period after each frame has been scanned. The video signals need not exist while these impulses are being transmitted; in fact, it is wise to stop them entirely during these periods. The line and frame impulses must be sufficiently different in character to be readily separated at the receiver and applied to the proper control circuits. In actual television systems, this difference involves making one type of impulse last a longer time than the other.

The three essential components of a television signal (the picture signal, the line synchronizing impulses, and the frame synchronizing impulses) may be transmitted in a number of different ways, but the signal arrangement shown in Fig. 4 comes nearest to satisfying the requirements of the television receiver. The r.f. carrier will be considered later and hence is not shown in this diagram. First of all, notice that this television signal is a pulsating d.c. signal with all its

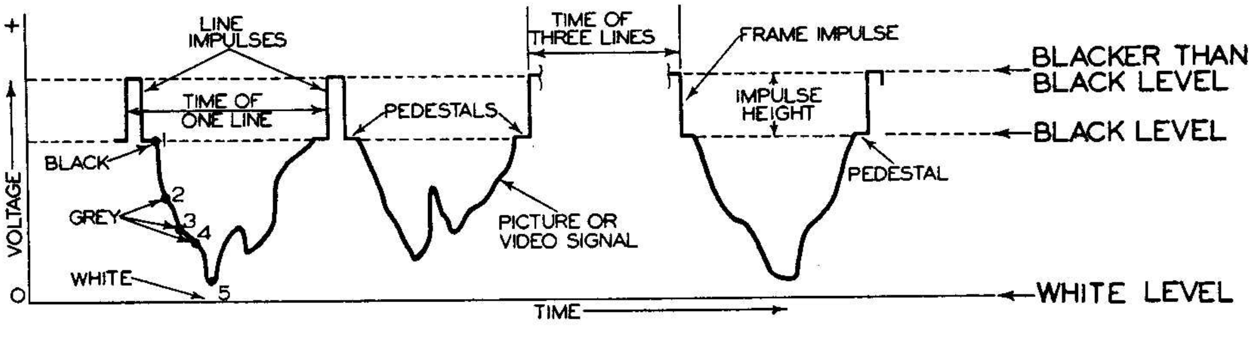


FIG. 4. This diagram shows the three essential components of a television signal—the video signal, the line impulse, and the frame impulse. This is a modulated d. c. signal. Since the picture signal voltage swings in a negative direction with increases in line brilliancy, we have what is known as a negative picture phase.

components above the zero-voltage line, which is known as the *WHITE LEVEL.* The video or picture signal varies between the *WHITE LEVEL* and the *BLACK LEVEL.* The synchronizing impulses are all between the *BLACK LEVEL* and what is commonly known as the *BLACKER THAN BLACK LEVEL.* The frame impulse lasts about three times as long as the time for one line. The BLACK LEVEL is 75% of the maximum television signal amplitude.

Notice that points 1, 2, 3, 4, and 5 along the video signal, corresponding to elements along one line of the picture being scanned, are for increasing values of brightness, with point 1 corresponding to a black elemental area on the picture, points 2, 3, and 4 for gray areas, and point 5 for a white area. When increases in brilliancy make the picture signal voltage swing in a negative direction in this manner, we say that the signal has a *negative picture phase.* The synchronizing impulses are kept in a region not ever occupied by the video signal in order to make possible the use of a biased diode or triode tube for separating these impulses from the video signal. Notice also that before and after each impulse the television signal voltage remains constant for a short interval of time. These constant-voltage components of a television signal are known as *pedestals.*

When a very-high-frequency r.f. carrier is modulated with the television signal shown in Fig. 4, the white components of the video signal will exist as low carrier currents, and the impulses will exist as large r.f. carrier currents. This type of modulation is known as *negative modulation,* and is the exact opposite of the positive modulation scheme used in transmitting sound signals. (In radio broadcasting, the largest carrier currents correspond to the loudest sounds, and low carrier currents represent weak sounds). Negative modulation is used in television to insure having synchronizing impulse signals which are sufficiently strong to over-ride any interference noises which may be present. Furthermore, experience has shown that negative modulation gives more accurate synchronizing control at the image reconstructor in the receiver, and makes it possible to build into the television receiver a simple circuit for providing the highly essential automatic gain control action.

The Cathode Ray Tube as an Image Reproducer

Although electromechanical methods of scanning and reproducing are perfectly feasible, these methods are far more cumbersome than purely electrical methods. Furthermore, the electrical methods, employing various forms of cathode ray tubes, are far more satisfactory for high-definition home television receivers than any mechanical system, hence, electronic systems are used exclusively.

The essential elements of one type of cathode ray tube being used for image reconstruction are shown in Fig. 5. They are: K—the cathode, which emits electrons when heated; F—the filament, which heats the cathode; A_1 and A_2—anodes which accelerate the electrons and focus them into a narrow beam; S—the fluorescent screen, which glows when hit by the electron beam; G—the control

electrode (commonly called the control grid even though it looks entirely different from the grid of an ordinary vacuum tube), which controls the number of electrons entering the electron beam and thus controls the brightness of the spot on the screen; V—the vertical deflecting electrodes, which move the beam up and down on the screen; H—the horizontal deflecting electrodes, which move the beam horizontally in either direction.

Electrode A_2 is always at a higher positive potential than electrode A_1. These high positive potentials serve to accelerate the electrons in the beam, giving them greater speed; at the same time, the difference in potential between A_2 and A_1 serves to focus the electrons into the desired narrow beam. Control grid G is always negative with respect to cathode K; the value of this negative potential determines the number of electrons which the cathode can force into the electron beam.

When proper voltages are applied to the various electrodes in a cathode ray tube, with all electrodes located symmetrically with respect to the central axis of the tube, the spot will be in the center of the screen. Increasing the negative voltage on control electrode G reduces the number of electrons in the beam and thus reduces the brightness of the spot. The negative bias on the control grid is usually set so that the screen is dark when no television signal is present.

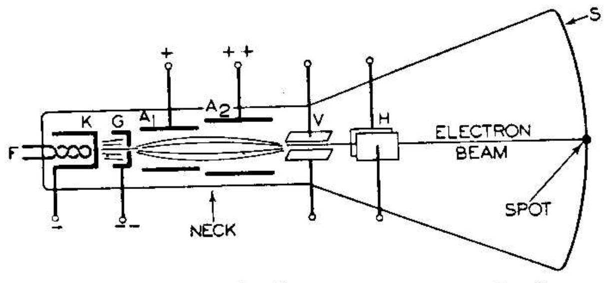


FIG. 5. Essential elements in a cathode ray tube used for image reconstruction in a modern television receiver.

The television signal must be applied in series with the negative grid bias in such a way that the spot will be dark each time a pedestal is transmitted; this condition is secured when the pedestals line up with the brilliancy cutoff point on the characteristic curve of the cathode ray tube. Video signals must make the control grid more positive than the cut-off voltage, thus varying the brightness of the spot on the screen. Synchronizing pulses must make the control grid more negative than the cut-off voltage, so the screen will be dark during the very short intervals of their duration (these intervals are, of course, too short to be noticed by the human eye).

The spot is in the center of the cathode ray tube screen only when there are no voltages on the vertical and horizontal deflecting electrodes.

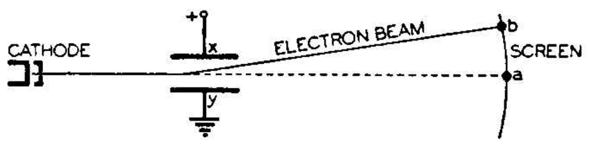


FIG. 6. An electron beam passing between two oppositely charged metal plates is always bent toward the positive plate.

Now let us see how these electrodes can be made to move the spot to any desired point on the screen. Referring to Fig. 6, notice that we have an electron beam traveling between two oppositely charged metal plates. Remember that the electrons in this beam have negative charges; this means that the positively charged plate will attract these electrons, bending the beam upward and causing it to strike the fluorescent screen at point b insead of at a, the center. The greater the voltage between these two deflecting plates, the more bending of the electron beam there will be.

But we know that this electron beam must be moved in a definite manner if it is to produce an image on the television screen. You will remember that the scanning process

in the television camera involves analyzing the scene element by element in a manner exactly similar to that in which our eyes read a printed page. First of all, then, we require a means for sweeping the electron beam gradually from left to right in a horizontal line, then quickly back again to the left, with this horizontal sweeping motion being repeated continually.

We can secure horizontal sweeping of the beam by varying either the electromagnetic or electrostatic field in the tube. The magnetic method will be studied later. We will now study electrostatic sweep which is obtained by applying to the horizontal deflecting plates of a cathode ray tube a voltage having the characteristics shown in Fig. 7; this is known as a *saw-tooth* (*or linear sweep*) *voltage.*

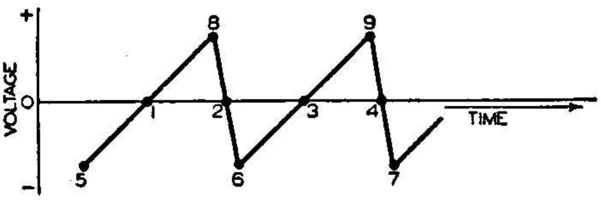


FIG. 7. Wave form of the saw-tooth voltage that is used for sweeping the electron beam back and forth in a television cathode ray tube.

Observe that this voltage is zero at points 1, 2, 3, and 4, is positive at points 8 and 9, and is negative at points 5, 6, and 7. If this voltage is applied to plates x and y in Fig. 6, and plate y is grounded, plate x will be positive when the voltage is following path 1-8-2, and plate x will be negative when the voltage is following path 2-6-3. Plate y will always be at zero or ground potential. We can think of the voltage wave in Fig. 7 as showing variations in the charge on plate x. When this charge is at point 1, the deflecting plates will have no effect upon the electron beam and the spot will be in the exact center of the screen. As the charge on plate x approaches the positive value at point 8, the electron beam will be attracted gradually and uniformly toward plate x. As the charge drops to zero again at point 2, the spot will move rapidly back to the center of the screen. From point 2 to point 6, plate x will become increasingly negative, repelling the beam and bending it toward plate y. From point 6 to point 9 the beam will move gradually from plate y toward plate x, and from point 9 to point 7 the beam will move rapidly back toward plate y again.

We have seen that a saw-tooth voltage of the form shown in Fig. 7 will produce the desired sweep of the electron beam. If this saw-tooth voltage is applied to horizontal deflecting plates H in Fig. 5, it will cause the spot to sweep slowly from left to right across the screen, then return rapidly to the left again. If this voltage is applied to the vertical deflecting plates V in Fig. 5, it will cause the spot to move gradually from top to bottom and return rapidly to the top again.

In later television Lessons in this Course you will study the special vacuum tube circuits that are used to produce these saw-tooth voltages used for electrostatic control of cathode ray tubes. None of these circuits are absolutely steady in frequency, however; it is therefore necessary to send impulse signals along with the television signal for the purpose of controlling and stabilizing the sweep circuits. One saw-tooth oscillator circuit is required for the horizontal or line sweep and another for the vertical or frame sweep. The line sweep circuit builds up its voltage uniformly from point 5 to point 1 to point 8 in Fig. 7; at point 8, corresponding to the end of the line, a line impulse arrives with the television signal and causes this voltage to drop back to point 6 rapidly. The building up of voltage starts again, only to be stopped at

point 9 by another line impulse. Since the drops in voltage are accurately controlled by the transmitter through the line impulses, we know that the electron beam in the reproducing device will be swept horizontally in exact synchronism with the scanning device at the transmitter. The vertical sweep circuit operates at a considerably lower frequency, and is controlled in the same manner by the frame impulses broadcast by the transmitter.

Now let us follow the movement of the spot on the screen of an actual television cathode ray tube as it sweeps back and forth and up and down under the influence of the impulse-controlled sweep circuits.

When the beam is under the control of the horizontal and vertical sweep voltages, we can consider its starting point to be point 1 in Fig. 8, at the upper left-hand corner of the screen. From this point the horizontal sweep voltage gradually allows the beam to "unbend" or return to the center of the top line, then gradually bends the beam in the opposite direction until the spot reaches the right-hand edge of the screen; during this action the vertical sweep voltage is gradually moving the spot in a downward direction a distance equal to the spacing between two lines.

At point 2 a line impulse arrives from the transmitter, causing the horizontal sweep voltage to move the spot almost instantly back to the left-hand side of the screen along the dotted-line path 2-3. This return motion is very rapid, but sometimes, if the receiver is not properly adjusted, it will produce on the screen a faint line which is known as the *retrace* or *fly-back line.*

This process continues for each other line until the spot is swept to point 36 at the end of the last line. At this time the first frame impulse arrives from the transmitter, stopping the gradual build-up of the vertical synchronizing voltage and causing the spot to move back up to the top of the screen. Even though this vertical sweep voltage drops back to its starting value at a rapid rate, the change does take more time than is required for a complete horizontal sweep. As a result, the spot actually takes a zig-zag path from side to side as it is being returned to the top of the screen. This zig-zag path is not ordinarily seen on the cathode ray tube screen, so for simplicity the ver-

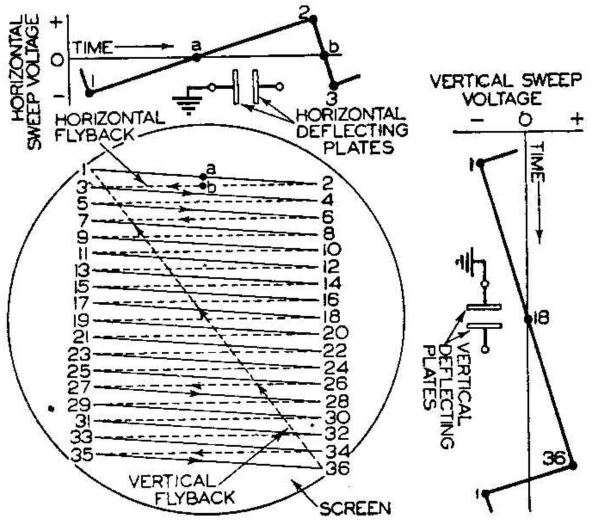


FIG. 8. The path traced on the fluorescent screen of a television cathode ray tube by an electron beam under the influence of horizontal and vertical sawtooth sweep voltages is shown in this diagram. The wave forms of the sweep voltages are shown above and at the right of the screen; these voltages are applied to the ungrounded deflecting plate in each case. Thus, when the ungrounded horizontal plate is highly negative (at 1), the spot will be at the extreme left side of the screen at point 1; when this plate is at zero potential (a), the spot will be at a in the center of the screen; when this plate is highly positive (2), the spot will be at the extreme right side of the screen at 2; when the saw-tooth voltage drops suddenly back to the highly negative value (2 to b to 3), the spot flies back from 2 to b to 3 on the screen. Likewise, when the ungrounded vertical plate is highly negative (1), the spot will be at the top of the screen at point 1; when this plate is at zero potential, the spot will be halfway down the screen at point 18; when this plate is highly positive (36), the spot will be at the bottom of the screen at point 36; when the saw-tooth voltage drops suddenly back to the highly negative value 36 to 1, the spot flies up from 36 to 1 on the screen over a zig-zag path which for simplicity is shown here as a straight line.

tical retrace is shown as straight-line path 36-1 in Fig. 8.

The scanning path just described, going from point 1 down to point 36 and then back to 1 again, constitutes one complete normal scanning of the scene. The entire process is repeated for each succeeding scanning.

No television picture signals exist while either a horizontal or a vertical impulse is being sent by the transmitter, hence the appearance of any retrace lines would only cause lines or diagonal streaks in the picture, marring the reproduction. The synchronizing impulses are applied to the control grid of the television cathode ray tube in the receiver in such a way that these impulses drive the grid highly negative, causing almost complete cut-off of the electron beam and thereby preventing either the horizontal or the vertical retraces from showing.

IMAGE DETAIL

A consideration of the processes of scanning and reproduction just described should make it clear to you that the video signal exists only while the spot is traveling from left to right along a line; at all other times the television transmitter is sending out pedestals and synchronizing impulse signals. The changes in the intensity of the video signal from one instant to another produce the essential picture detail; the more changes there are per line for an actual given scene being scanned, the greater will be the amount of detail in the reproduction.

Naturally it would be useless to have considerable detail in a single line if there were only a few lines in the complete picture. This means that if greater detail is desired, the number of lines per picture and the number of changes per line must be increased proportionately. Thinking of a reproduced image as being made up of a number of square dots, somewhat like the image in Fig. 3, we arrive at the basic fact that it is desirable to have as many dot impressions per inch along a line as there are lines per inch.

Frequency Range. We can now consider the maximum frequency involved in a video signal. Since frequency is expressed in terms of cycles per second, we must review the fundamental definition of one cycle: *A cycle is a complete reversal or change.* If the elemental areas along a line of a televised image are alternately light and dark like a checkerboard, it will take two elemental areas to give a change. This means that the shortest cycle in a television image is equal to the time duration of two elemental square areas along a line. We seldom have a perfect checkerboard pattern in television, and hence it may take a longer interval of time—a whole line, half a frame or an entire frame—in order to give the change which constitutes a cycle. We have a maximum number of cycles when the elemental square dots are alternately light and dark, so by assuming this condition to be present we can figure out the maximum video frequency. Let us see what this frequency is.

In this country, 525 horizontal lines are the standard for television. If the picture were square, there would be 525 times 525, or a total of 275,625 square dot elements in this square picture. But television studios use standard motion picture film for some transmissions, and the frames in motion picture film are never square. These frames are always wider than they are high; in fact, they are actually 1/3 wider than their height, so that a projected picture which is 3 feet high will be 4 feet wide. This ratio of width to height is known as

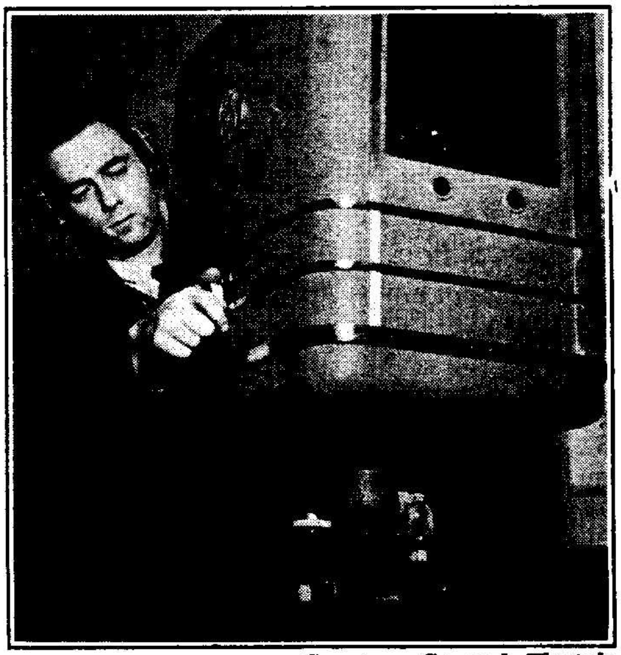
the *aspect ratio*. The standard 4/3 aspect ratio for motion pictures has also been adopted for television; since this will increase the length of each line by the factor 4/3, we must multiply the value 275,625 by 4/3. This gives us 367,500 square dot elements in a standard television picture.

Television standards also require 30 complete pictures per second. Multiplying 367,500 by 30 gives us 11,025,000 elements per second. Since 2 dots are required to give the shortest possible cycle, we divide 11,025,000 by 2, and get 5,512,500 per second as our maximum video frequency under the conditions so far presented.

This last figure assumes, however, that video signals are being transmitted all the time. We know that this is not true, for about 14% of the transmitting time is used for the horizontal flybacks. This leaves 86% of the total time for video signals, and means that our maximum frequency of 5,512,500 must be sent in 86/100 of a second. We must divide 5,532,500 by .86 giving about 6,485,000 cycles per second as the true maximum frequency for a 525-line image.

Investigation has revealed that for the average size of television image, the maximum frequency can be only about 60% of the value just specified without seriously impairing the quality of the image. Hence, a maximum frequency of 3.9 mc. is satisfactory for some television receivers. However, many high-definition receivers are capable of handling the full video 4.25-mc. band of broadcast television signals.

Theoretically, the lower limit of the video frequency to be transmitted is zero, corresponding to a scene which is all the same brightness (all white, all black, or all the same shade of gray). It is very difficult, if not impossible, to construct apparatus which will handle frequencies from 4.25 megacycles right down to zero, but practical experience has shown that a lower frequency limit of about 10 cycles per second will give satisfactory reproduction of ordinary scenes if the video frequency amplifier in the receiver is properly designed.



Courtesy General Electric

A typical television camera in operation.

FLICKER

The human eye is peculiarly sluggish in its response to moving objects, for it continues to see an object even after the object has disappeared. Motion pictures depend upon this *persistence of vision* characteristic of the human eye; 24 separate still pictures are flashed upon a motion picture screen each second in sequence, but the eye sees a continuous action rather than a series of separate pictures. The eye can detect individual views up to a rate of about 10 pictures per second, but above this value the scenes blend together, accompanied by pulsating light impressions which give the effect of flicker. At about 20 pictures per second the blending of pictures into motion is

almost perfect as far as the eye is concerned; flicker is greatly reduced at this rate but still is not entirely absent. Even at 24 pictures per second, the standard in the motion picture industry, flicker can still be noticed. It is for this reason that motion picture projectors have a shutter in front of the lens which breaks up each still picture into two separate views, giving the effect of 48 pictures per second although only 24 of them are different.

In television, the frequency of the available a.c. power has considerable effect upon the choice of a frame frequency (number of pictures transmitted per second). Since the power line frequency in this country is standardized at 60 cycles, ripple voltages at this frequency or some multiple of it will get into the video signal and the sweep voltages, tending to cause ripple effects, wobbling of the picture, and random movement of bright bands on the image if the number of pictures is increased to 48 or even 72 in order to eliminate flicker. By using a frame frequency equal to some submultiple of 60 (such as 30 or 20) or some multiple of 60 (such as 60, 120 or 240), these ripple effects can be removed or at least made stationary so they will be less objectionable. Frame frequencies of 20 or 30 are still too low to eliminate flicker entirely; on the other hand, a frame frequency of 120 pictures per second would increase the maximum frequency of the video signal to an extremely high value. There is left, then, a scanning rate of 60 complete frames per second, which imposes quite a burden upon the transmitting system insofar as maximum frequency range is concerned. With a 525-line image being scanned 60 complete times each second, the upper frequency limit for high definition becomes more than 8.5 megacycles. It is not impossible to make amplifiers which will handle a range of from 10 cycles to 8.5 megacycles, but the cost of these is so high that the production of inexpensive television receivers becomes a serious problem.

How Interlaced Scanning Reduces Flicker

A simple scanning trick which makes the maximum video signal frequency correspond to that of a 30-picture-per-second transmission while still keeping the scanning rate at 60 pictures per second is the solution which television engineers have developed for the problem of flicker. In this system, which is known as *interlaced scanning*, only half of a picture is transmitted during one complete scanning; the other half is transmitted in the next complete scanning. A simple scheme has been developed whereby lines 1, 3, 5, 7 and all other odd lines are covered during one scanning, and lines 2, 4, 6, 8 and the other even-numbered lines during the next scanning. Two complete scannings are therefore required to cover every elemental dot area on the scene being televised. At the receiver there must likewise be two complete scannings to give a complete reproduction of the image. With interlaced scanning, the frame or picture frequency is 30 per second since that is the number of complete pictures transmitted. For each complete picture the scene is scanned twice, so the *field frequency*

(*vertical sweep frequency*) is 60 times per second.*

The two requirements for double interlaced scanning of a given number of lines per second at a given frame frequency are: 1, an odd number of lines per picture; 2, a vertical scanning rate which is twice the frame frequency. This automatically gives scanning of the odd-numbered lines during one vertical sweep and scanning of the even-numbered lines during the next vertical sweep, with odd and even line scanning alternating automatically. An example will best illustrate how this is done; since an example based upon a 525-line image would be too cumbersome, a lower number of lines will be used to illustrate the principles involved.

Suppose that we divide our picture into 10 lines, as shown in Fig. 9A, and that we scan this complete scene 10 times per second (giving a vertical sweep frequency of 10 per second). This means that one complete scanning of the scene, starting at point 1, proceeding to 2, 3, 4, 5. . . . . 18, 19, 20, and then returning to 1, will take 1/10th of a second. *Assuming that fly-back time is negligible* in these examples, we can also say immediately that it will take 1/100th of a second to scan one line, moving from point 1 to point 2 and back to the start of the next line at point 3.

Suppose, now, that we scan this same scene (having an even number of lines), 20 times per second by doubling the vertical sweep frequency without changing any of the other conditions in Fig. 9A. We will still be scanning the same total number of

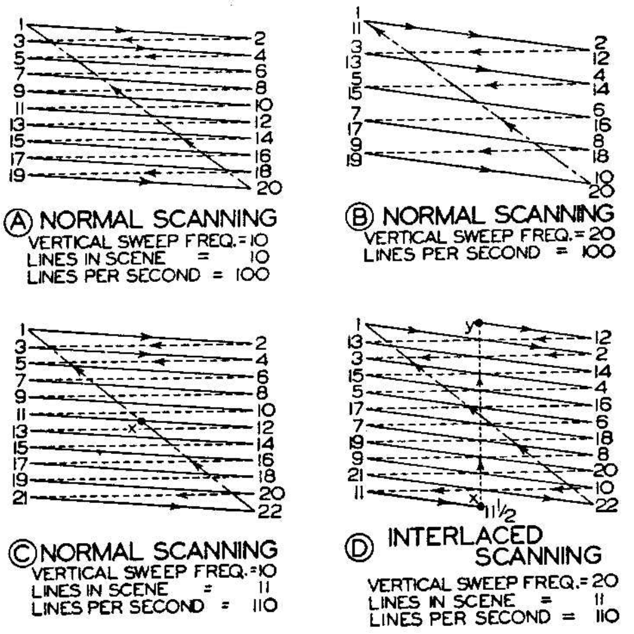


FIG. 9. These diagrams show that interlaced scanning can occur only when there is an odd number of lines in the scene and the vertical sweep frequency is twice the rate for normal scanning. Under these conditions, the same number of lines is transmitted each second with either normal or interlaced scanning.

lines per second, and it will still take 1/100th of a second to scan one line, but now only 5 lines will be covered in one complete scanning from top to bottom. Referring to Fig. 9B, the scanning path starts at 1 and goes to points 2, 3, 4, 5, 6, 7, 8, 9, and 10 during one complete scanning of the scene. Vertical fly-back now brings us to point 11 at the upper left-hand corner and we cover exactly this same scanning path for the second scanning of the scene. A television system using an even number of lines per picture cannot secure interlaced scanning by doubling the vertical sweep frequency.

Now let us see what happens when we have an odd number of lines (11) per picture and we use a vertical sweep frequency of 10 per second again, as indicated in Fig. 9C. All 11 lines are covered in one complete scanning, and vertical fly-back takes us directly from point 22 back to the starting point at 1.

Next, suppose we double the verti-

* A *field* is the area covered during one vertical sweep of the scene. In normal scanning, the field is the entire scene; in double interlaced scanning, the field is only half the scene.
A *frame* is one complete scanning of every elemental area in a scene. In normal scanning, this occurs for each vertical sweep; in interlaced scanning, two vertical sweeps are required for a frame.

cal sweep frequency, giving 20 complete scannings of the picture per second without changing the total number of lines transmitted per second. This doubles the speed at which the scanning spot is moved downward, so that we will arrive at point x in Fig. 9D (at the bottom of the picture) in exactly the same time it took to reach point x in the middle of the picture in Fig. 9C. In Fig. 9D, however, we have scanned only half the lowest line when vertical fly-back moves the spot up to point y for the following scanning. This time we scan along path 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, and 22, midway between the lines scanned the first time; *we are thus securing interlaced scanning of the complete scene.* From point 22 the spot goes back to point 1 for the start of the next complete scanning.

Interlacing twice, as illustrated in Fig. 9D, is considered standard practice; to secure this without changing the total number of lines scanned per second (without changing picture detail), the vertical scanning frequency must be twice the frame frequency and there must be an odd number of lines per frame. If the vertical scanning rate is made three times the frame frequency and if the number of lines per frame is not exactly divisible by three, we secure triple interlacing. With the vertical scanning frequency increased to four times the frame frequency, quadruple interlacing can be secured.

Now let us consider interlaced scanning in terms of the standards in use in this country for television. With 525 lines per frame, a vertical scanning frequency (field frequency) of 60 per second, and double interlaced scanning, the total number of lines scanned per second must correspond to that scanned normally with a frame frequency of 30 per second. Multiplying 525 by 30 gives 15,750 as the total number of lines scanned per second in American television systems. This means that the *frequency of the horizontal sweep is 15,750 cycles per second,* and the *vertical scanning frequency is 60 cycles per second.*

The detail in the image will correspond to that of 30 complete scannings per second of all lines in a 525-line image.

In an actual modern television system, a few lines at the top and bottom of each picture are blanked out by the blanking signal associated with the vertical synchronizing impulse, for reasons which will be taken up later. The synchronizing impulse itself prevents vertical fly-backs x-y and 22-1 in Fig. 9D from being visible.

Brightness and Contrast Controls

It is essential that the television signal which is applied between the control grid and the cathode of the television cathode ray tube shall be *pulsating d.c.* and have a *positive picture phase,* so that synchronizing impulses will cause darkness, and video signals will give various degrees of spot brightness. Another requirement for faithful reproduction of a televised scene is that the pedestals shall all line up with each other at the input to the cathode ray tube despite variations in the brightness of a scene. For example, the pedestals at the output of the video demodula-

tor in a television receiver should be the same voltage for a brightly-lighted scene (Fig. 10A) as for a dimly lighted scene (Fig. 10B). Incidentally, with the exception of a reversal in phase, the signals shown in Fig. 10 have essentially the same form as those produced by television transmitters.

Now let us see how a cathode ray television tube reacts to signals of the type shown in Fig. 10 when the pedestals are lined up with each other. Remember that the various anodes in this tube have operating voltages which serve to focus the electron beam to a small spot on the screen, and that the negative voltage applied to the control grid of the tube determines the brilliance of this spot. The control which this grid has upon spot brilliancy is more or less linear with respect to the applied grid voltage, except that complete cut-off or darkening of the spot occurs at a definite high negative grid bias voltage. The graph in Fig. 11 shows these facts; note that reducing the negative bias on the control grid (driving it in a positive direction) increases the spot brilliancy. Points 2, 3, and 4 are increasingly brilliant, and correspond to increasingly positive control grid voltages. This E_g-BRILLIANCY characteristic is quite similar to the E_g-I_p characteristic curve of the average triode vacuum tube.

The negative bias on the control grid of a television cathode ray tube must be so chosen that the pedestals in the applied television signal will be at the brilliancy cut-off point (point 1 in Fig. 11) on the E_g-BRILLIANCY characteristic curve of the tube. Under this condition the video signal will swing the grid more positive than cut-off, giving various degrees of brilliancy, and impulse signals will drive the grid more negative than cut-off (into the blacker-than-black region).

When the video portion of the television signal shown in Fig. 11 is acting on the grid-cathode of the cathode ray tube represented by this characteristic curve, the instantaneous control grid voltage will vary between points 1 and 5 on this curve, and spot brilliancy will vary over the region indicated as B. The impulses associated with this television signal swing the grid beyond the apparent cut-off point (beyond 1) and hence cannot produce a spot on the screen. As long as the pedestals line up with the cut-off point, impulses will not produce a visible spot even with weak video signals, and weak video signals corresponding to a dim line or a dark scene will cause brilliancy to vary in the desired manner over the lower portion of the characteristic curve, such as between points 1 and 2.

Suppose that the television signal in Fig. 11 were applied in such a way that the pedestals lined up with point 2. The video signal would swing the

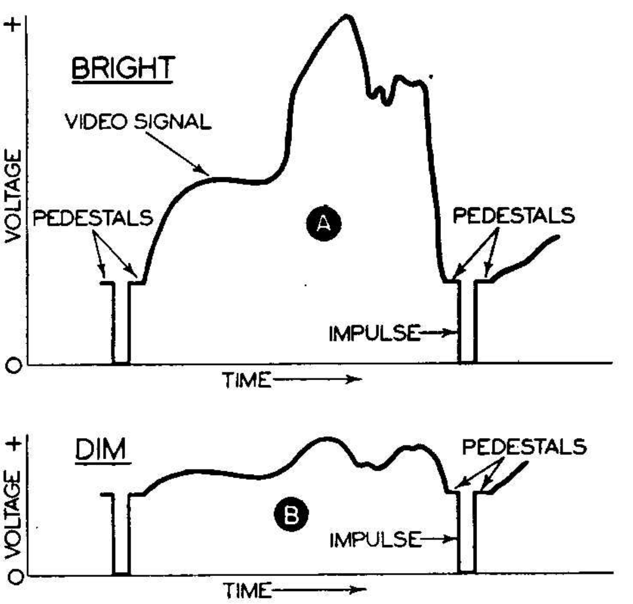


FIG. 10. The television signal which is applied between the grid and the cathode of a cathode ray tube must have a constant pedestal voltage for scenes with all degrees of brightness, and must have a positive picture phase as shown here, so that the video signal will be positive with respect to the pedestal voltage, and the impulse signals will all be more negative than the pedestal voltage.

grid voltage positively from point 2 up along the curve to point 6, which is quite all right, but the impulses would only swing a small amount beyond cut-off and would not darken the spot completely. As a result, both the line and frame retraces would be clearly visible at the beginning and end of each line and frame. Obviously this is not a desirable operating condition.

Now let us consider another condition, that where the pedestals are beyond cut-off and line up with point O. Portions of the video signal will now swing into the dark region beyond cut-off, causing dimly-lighted portions of a scene to appear black instead of gray. Obviously this operating condition is just as undesirable as that where the pedestals are to the right of cut-off.

The television signal at the input to the cathode ray tube in a television receiver can be shifted in two different ways in order to make the pedestals line up with the black level (cut-off) of the cathode ray tube. One method involves adjusting the fixed

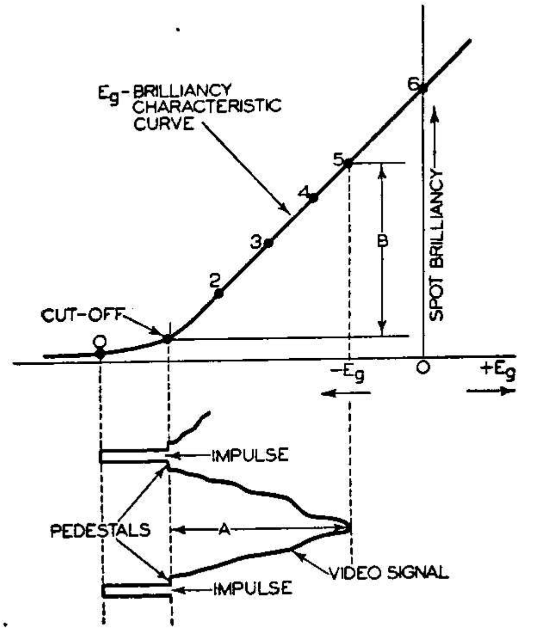


FIG. 11. Typical grid voltage-brightness characteristic curve for a cathode ray tube in a television receiver. Point 1 is considered the brilliancy cut-off point for the tube, as it corresponds to a spot brilliance weak enough to be indistinguishable to the human eye.

C bias on the cathode ray tube; the control in a television receiver which changes this bias is commonly known as the *brilliancy control,* for the most noticeable effect of changing the bias is a change in the brilliancy of the reproduced image. We can also shift the pedestals in one direction or the other to make them line up with the cut-off point by changing the amplification (gain) of one or more stages through which the television signal passes in the receiver. The receiver control which changes gain is commonly known as the *contrast control,* for its most noticeable effect is a change in the amount of contrast between bright and dark areas of the reproduced image.

We will want to decrease the amplification if screen brilliancy is too great or if the signal is so strong that it drives the control grid of the cathode ray tube positive (this causes the grid to draw current, narrowing the range of frequency response). If receiver amplification is too low, giving us a gray picture with insufficient contrast, we will want to increase amplification until we get the desired contrast between light and dark areas on the picture.

Another requirement for a clear image is that the electron beam be focused to a clearly defined spot of the correct size on the screen. An adjustable control called the *focus control* is usually provided to correct for errors in focusing due to natural aging of the cathode ray tube or to other causes.

The adjustable controls required in the sight section of a television receiver are thus the *brilliancy control,* the *contrast control,* the *focus control,* and the *tuning control.* These must be adjusted to give a reproduced image which has the proper brilliancy and the correct contrast between elements along a line, with no line and

frame retraces visible. When the brilliancy control is adjusted, the contrast control will also require resetting in most cases, and vice versa, for there is some interaction between these two controls.

Television Signal Standards

In order for a television system to be successful, the receiver must be easy to adjust, the cost of the receiver must be relatively low, and the transmitter must have as much control as possible over the receiver. This last requirement means that the receiver and transmitter must be interlocked and synchronized. Furthermore, the type of transmission employed must be standardized to a certain extent, for radical changes in the method of transmission might make all existing television receivers obsolete. At the same time, it would not be advisable to set up standards in such a way that it would be impossible to make improvements in the transmitting and receiving circuits. Standards are essential for a successful television system, but these standards must be sufficiently broad to permit future improvements which might make interlock and synchronism more reliable or increase the definition of the reproduced scene.

A set of television standards which takes all these factors into consideration has been approved by the Radio Manufacturers' Association (R.M.A.) for television systems in the United States and is required (as far as transmitters are concerned) by the FCC. There is no assurance that these standards will remain as originally set up indefinitely. Changes are bound to come, but immediate changes will not be so drastic as to make receivers obsolete in the near future. Minor changes in transmitters will require little or no changes in television receivers.

1. *Television Channel Width; Channel Allocations.* The present standards provide for essentially single side-band transmission and reception (partial suppression of one set of side frequencies results in *vestigial side-band transmission*), for with this method of operation, sufficient detail for a satisfactory image can be transmitted in a definite channel width of 6 *megacycles.* Twelve 6-megacycle-wide channels have been allocated by the Federal Communications Commission for television transmitters, as follows: 54 to 60, 60 to 66, 66 to 72, 76 to 82, 82 to 88, and seven other channels from 174 to 216 mc. A number of very-high-frequency and microwave channels have been allocated for television relay purposes such as linking the television studio to the transmitter by radio, linking the remote pick-up point to the transmitter by radio, or linking together television stations in different cities and towns to form a network.

2. *Video and Sound Carrier Spacing.* Obviously the audio and video signals which make up a modern television program cannot be modulated on the same r.f. carrier; each must have its own carrier. By agreement *the sound carried must be exactly 4.5 megacycles higher in frequency than the picture carrier.* To prevent interference between adjacent television channels or between a television carrier signal and services operating on adjacent carrier frequencies, it has been further agreed that there must be a .25-megacycle-wide guard band at the high-frequency end of each

television channel. All these facts are illustrated by the chart in Fig. 12, which shows a typical distribution of signals in one 6-megacycle-wide television channel.

3. *Frequency Relation Between Video and Sound Carried.* An example will best illustrate the frequency relationship existing in a television channel. Suppose that the 76- to 82-megacycle channel is assigned to a particular television station. To give the required .25-megacycle guard band at the high-frequency end, the audio signal carrier must be placed at 81.75 megacycles. According to the standards, the video carrier must be 4.5 megacycles lower, or at 77.25 megacycles. Since it is not as yet practical to remove all of the side frequencies below the frequency of the video carrier, a portion of the channel must be provided for those frequencies which cannot be removed. This portion is indicated by the cross-hatched lines in Fig. 12. With this arrangement of a 6-megacycle channel, the frequency range of television equipment can be improved up to a maximum of about 4.25 megacycles without making existing television equipment obsolete.

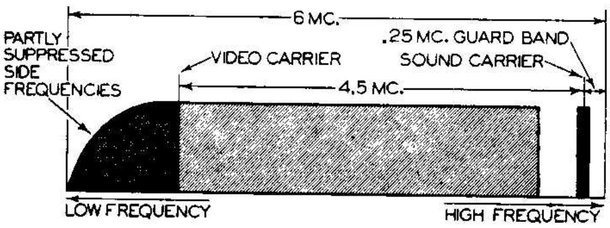


FIG. 12. Distribution of signals in a 6-megacycle-wide television channel.

4. *Type of Modulation; Black Level.* Negative modulation of the picture carrier signal is standard for the United States. As we have already pointed out, negative modulation means that *bright elements of a picture are transmitted at low carrier levels,* and *dark elements at high carrier levels.* The R.M.A. standards further specify that the black level or pedestal level at the transmitter shall be at a definite carrier level which remains fixed regardless of variations in impulse signals or in video signals. The black level at any one point in a television system is the voltage which must exist at that point to give a just barely visible spot on the screen of a properly adjusted receiver.

Furthermore, the d.c. level of the video signal depends on the average brightness of the scene being televised. Hence it is not possible to refer to "percentage of modulation" in a television system in the same way as in a sound a.m. system. In television, the various picture and sync levels are given merely as percentages of the peak carrier output, not as percentages of modulation.

5. *Impulse Amplitude.* Both line and frame impulses must be transmitted as carrier values higher than unmodulated carrier level (black level). These impulses extend from 75% (black level) to 100% of the peak carrier amplitude. The video signals may vary in amplitude from the black level down to 15% of the carrier level or lower. The general appearance of a typical modulated video carrier signal as it is fed into the television transmitting antenna is shown in Fig. 13. When there is no modulation, the r.f. carrier will have amplitude A, corresponding to the black level. Any increases in carrier amplitude must be for the synchronizing impulses; and decreases in carrier amplitude must be for the video signals. Since we are primarily interested in the impulse and video signals in any study of television, we can neglect the r.f. carrier itself and concentrate our attention on its modulation envelope.

6. *Line, Frame, and Field Frequencies.* The establishment of standard

values for these three frequencies was based upon the need for high image definition with a minimum of flicker. A vertical scanning frequency (field frequency) of 60 times per second is now standard, for this value minimizes any trouble due to 60-cycle power ripple. (In England, where 50-cycle power lines are used, the field frequency has been standardized at 50 vertical scannings per second.) Since double interlaced scanning is used in the United States, two field sweeps are required to analyze all of the details once in a particular scene; these two vertical or field sweeps constitute a frame (one complete transmission of the picture), and consequently the standard for the frame frequency is 30 frames per second. As we have already seen, there are 525 lines per frame; this means that there are 262½ lines per field. With a 525-line picture being sent 30 times each second, the line frequency becomes 525 times 30, or a total of 15,750 lines per second.

Since it is desirable to obtain both the line and field signals from a single standard-frequency source, the value 525 was chosen as the number of lines per frame because it permits the use of comparatively simple frequency divider circuits in the master synchronizing generator at the transmitter.

7. *Aspect Ratio.* This ratio has been standardized at 4/3, corresponding to existing motion picture standards and giving a width-to-height ratio of 4 to 3.

8. *Synchronizing and Equalizing Impulses; Blanking.* The ability of a television transmitter to control the reproduced picture at the receiver depends entirely upon the synchronizing impulses. Many years of research have been spent on this problem, and many different forms of impulse signals have been tried. The standard synchronizing impulses shown in Fig. 14 have been found best suited to present and future requirements of television in this country. Pattern A shows, among other things, the synchronizing impulses recommended for the end of a frame; these will move the spot up to the top of the picture along the retrace path for the beginning of a new frame. Pattern B shows the impulse signal sequence recommended for the end of the first half-frame (the end of the first field); this moves the spot from the bottom to the top of the picture for the beginning of the second interlaced field scanning. A careful study of the diagrams in Fig. 14 will reveal five outstanding characteristics of a television signal:

I. The horizontal synchronizing impulse which is transmitted at the end of each line is not exactly rectangular. The enlarged diagram in Fig. 14D shows the exact shape of this synchronizing signal.

II. The video signal is blanked out for a short interval before and after transmission of the horizontal synchronizing impulse at the end of a line, in order to insure blanking out of the horizontal retrace. The total time for this horizontal blanking shall be about 14% of the time from the start of one line to the start of the

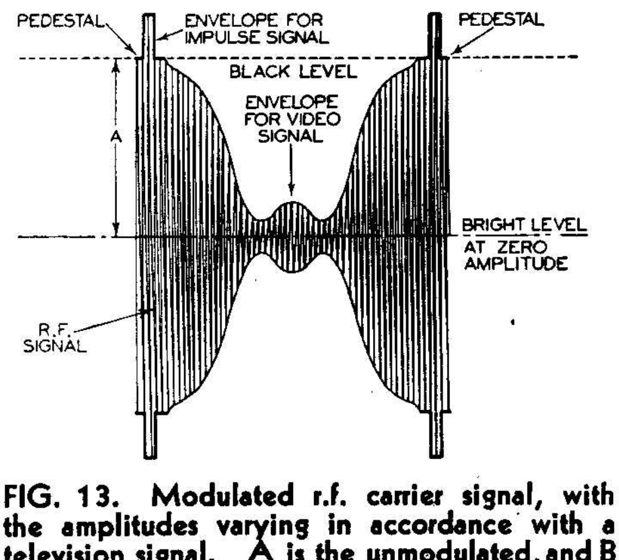


FIG. 13. Modulated r.f. carrier signal, with the amplitudes varying in accordance with a television signal. A is the unmodulated, and B the peak carrier level.

RMA STANDARD TELEVISION SIGNAL

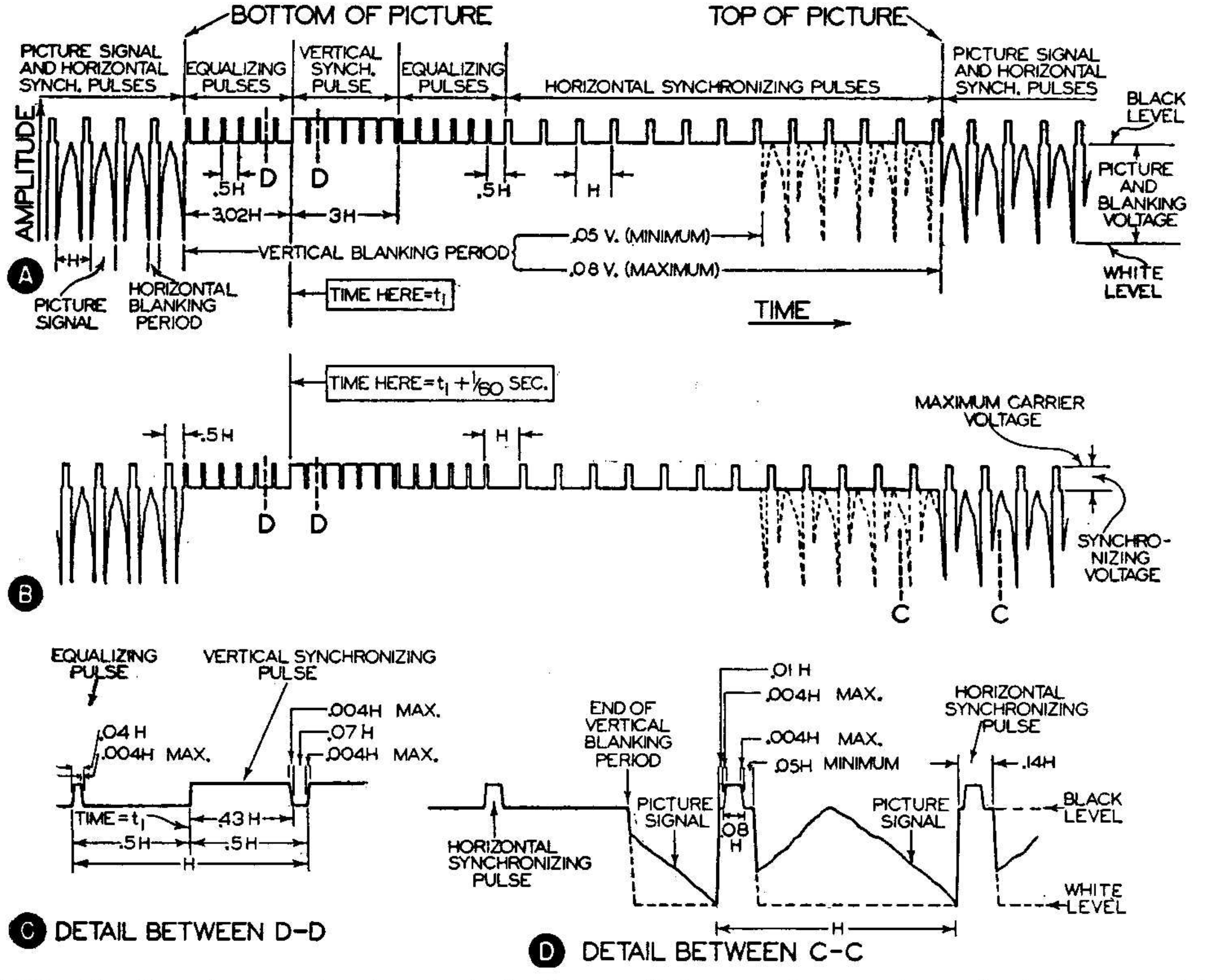


FIG. 14. Specifications for the standard television signal for 525-line pictures transmitted at the rate of 30 frames per second with double interlaced scanning, giving 60 fields per second. In these diagrams H is the time from the start of one line to the start of the next line, and is equal to 1/15,750 second. The time from the start of one field to the start of the next field is 1.60 second.

Diagrams A and B show blanking and synchronizing signals in regions of successive vertical blanking pulses. The black level is about .75 of the synchronizing pulse amplitude. Horizontal dimensions in these diagrams are not drawn to scale. The receiver vertical retrace will be complete at the end of about .07 V during the vertical blanking period. The length of the vertical blanking period produced by the transmitter may vary between .05 V and .08 V. The leading and trailing edges of both the horizontal and the vertical blanking pulses have slopes (not indicated in A and B), which should be kept as steep as possible.

Diagram C is an enlarged detail view, drawn accurately to scale, of the signal between points D-D in diagrams A and B.

Diagram D is an enlarged detail view, drawn accurately to scale, of the signal between points C-C in diagram B.

next line (this is designated as 14H at the right in Fig. 14D). Note that the horizontal synchronizing impulse occupies about half of this blanking time, and that the front (leading) edge of the impulse is near the start of the horizontal blanking. The two portions of this blanking signal which are on each side of the horizontal synchronizing pulse are known as *pedestals*, and are originally at the black level.

III. The vertical synchronizing impulse exists for an interval of three lines, but this impulse is divided into six small pulses, each acting for half a line. This serrated pulse is shown in Fig. 14A. Each vertical impulse is divided into six small pulses or serrations in order to maintain horizontal

impulses at all times. These serrations will be explained in detail later.

IV. Six equalizing impulses precede and six follow each vertical impulse period. The purpose of these will also be covered later.

V. The vertical blanking period starts slightly ahead of the first equalizing impulse and extends considerably beyond the last equalizing pulse; this vertical blanking period should take between 5% and 8% of the time for one vertical sweep. Note that horizontal synchronizing pulses are transmitted during the latter portion of the vertical blanking period.

Explanation of Standards. As long as we have 60 vertical sweeps per second, interlaced scanning will continue automatically throughout a transmission. The vertical fly-backs or retraces will be 1/60th second apart; they may occur either near the beginning or near the end of the vertical synchronizing impulse interval, but must occur at the same point in each impulse (this point is controlled by the design of the receiver).

Although the leading (left-hand) edge of the vertical synchronizing impulse in Fig. 14A is directly above the leading edge of the vertical synchronizing impulse in Fig. 14B, these actually occur 1/60th of a second apart due to interlacing. For this reason, the horizontal impulses at A and B in Fig. 14 are not in line.

Experience has shown that no matter what happens, the horizontal or line synchronizing impulses must not stop even for a single line. If the vertical synchronizing impulse were made three lines long without breaking it up, no horizontal impulses would exist for this period. To avoid the situation, the vertical impulse is serrated or separated into six smaller impulses.

To visualize why the vertical impulse must be broken up, let us first assume that it is broken up into three impulses as shown in Fig. 15, and see what occurs under this condition. For the moment we will forget about the equalizing impulses. Pattern A in Fig. 14 shows the last horizontal synchronizing impulse (just before the bottom of the picture) as being one whole line ahead of the start of the vertical blanking period, and pattern B shows this last horizontal impulse as only half a line ahead of the vertical blanking period; these are actual conditions for successive field sweeps, so we must consider them in Fig. 15. Line impulses must exist for the entire vertical blanking period; this means that there should be line impulses at points 2, 3, 4, and 5 in Fig. 15A. At each of these points there is a break or serration in the vertical impulse; since the leading edge of an impulse or serration is sufficient to control the horizontal sweep in the receiver, this will give adequate control of the horizontal sweep.

When we turn to pattern B in Fig. 15, however, we find that horizontal impulses should occur at points 2, 3, and 4. There are no steep leading edges at these points to control the line sweep, and consequently three serrations in the vertical impulse are not adequate for pattern B, which occurs for every other scanning of the picture. If the vertical impulse is divided into six parts as shown in Figs. 14A and 14B, we secure the desired steep front at points 2, 3, and 4 in pattern B in Fig. 15.

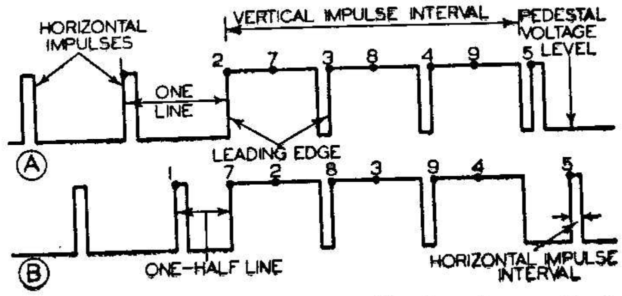


FIG. 15. These diagrams tell why the vertical synchronizing impulse signal must be broken up into six smaller impulses.

The vertical synchronizing pulse is chopped into segments by the application of a special signal having a rate twice that of the horizontal synchronizing signal. Because of the difficulty of synchronizing this signal exactly with the vertical pulse, this twice-normal signal exists somewhat before and after the vertical pulse as a series of horizontal synchronizing pulses at half-line intervals. Then, it is sure to properly cut up the vertical pulse. In Fig. 14A, these additional pulses are labeled "equalizing pulses." A pulse one-half a line from the proper one is ignored at the receiver; the sweep oscillator responds only to the pulse that occurs at the proper time to maintain the horizontal synchronization.

Television Receiver Circuits and Controls

Let us imagine that a radio wave having characteristics similar to those shown in Fig. 13 is being broadcast by a television transmitter, and consider just how this would be received and converted into an image by a television receiver having the essential sections shown in Fig. 16. First of all, the receiving antenna must be designed for efficient operation at the very-high frequencies employed in television. The radio waves radiated by the transmitter are generally polarized horizontally, and can therefore be picked up by a horizontal doublet antenna. Ignition interference from automobiles is a serious problem in cities and towns, and consequently the horizontal pick-up section should be located as far as possible from these sources of interference. For the same reason, the vertical transmission line must be shielded or otherwise designed so as to prevent pick-up of vertically-polarized interference signals. The antenna and its transmission line must be designed for efficient operation in the desired television channels and must have reasonably flat response over the entire 6-megacycle channel occupied by one station.

Either a tuned-radio-frequency circuit or a superheterodyne circuit could be employed for the r.f. amplifier section of a television receiver (ahead of the video demodulator), but when sight and sound signals are transmitted on carriers only 4.5 megacycles apart, good selectivity is highly essential. Superheterodyne circuits will provide this required selectivity and the necessary video pass band with a minimum number of stages, and consequently the superheterodyne circuit is used almost exclusively for simultaneous sight and sound (television) reception.

A practical superheterodyne circuit for a television receiver will have a preselector amplifying stage or at least one tuning circuit ahead of the mixer-first detector. This preselector must have essentially flat response over a 6-megacycle band, and must have sufficient selectivity to keep out television signals in other channels which could produce image interference.

To produce an i.f. signal, we naturally require a local oscillator; this must be reasonably stable in frequency. Since we feed two different r.f. carrier signals (one for sight and the other for sound) into the mixer-first detector, we get out two i.f. signals, one carrying the picture modulation and the other the sound modulation.

The local oscillator frequency will be *higher* than both the sound and

picture carrier frequencies, according to the accepted standards. The video i.f. value will be about 26.4 mc.; this means that if the incoming video carrier is 77.25 mc., the local oscillator frequency will be 103.65 mc. Since the sound carrier is 4.5 mc. higher than 77.25 mc., or is 81.75 mc., the i.f. value for sound signals will be the difference between 103.65 and 81.75, or an audio i.f. value of 21.9 megacycles. By using two separate i.f. channels, one tuned to 21.9 mc. and the other to about 26.4 mc., we automatically separate the two signals. Notice that the video and audio i.f. signals differ by 4.5 megacycles, just as did the video and audio carriers. Since the maximum deviation of the f.m. audio i.f. signal is 25 kc., this i.f. amplifier can be quite selective as compared to the preceding circuits. Too much selectivity is not desirable, however; the sound i.f. channel must be sufficiently broad to allow for a certain amount of drift in the local oscillator frequency.

You will recall (Fig. 12) that the entire band of side frequencies *above* the video carrier frequency is transmitted; this upper sideband extends for 4.25 megacycles according to present-day standards, so we have side frequencies in the range from 77.25 megacycles to 81.50 megacycles in the example we are analyzing. In the video i.f. amplifier this band will extend from 26.4 mc. (the video i.f. carrier value) to 22.15 mc. The video i.f. amplifier should therefore be flat in response from 22.15 mc. to 26.4 mc., and the sound i.f. amplifier which is tuned to 21.9 mc. must be sufficiently selective to eliminate 22.15-mc. video i.f. signals.

The sound i.f. amplifier will be followed by limiter stages (if used), a discriminator, an audio amplifier, and a loudspeaker, and will probably have automatic volume control on its i.f. stages. Since this sound i.f. amplifier is highly selective and is interlocked with the video i.f. amplifier through the common oscillator and mixer-first detector, the tuning of a television receiver simply involves tuning for maximum volume and clarity of the sound signal; this automatically tunes in the video signal properly.

Automatic gain control (a.g.c.) is a very desirable additional circuit in a television receiver. Like automatic volume control in an ordinary sound

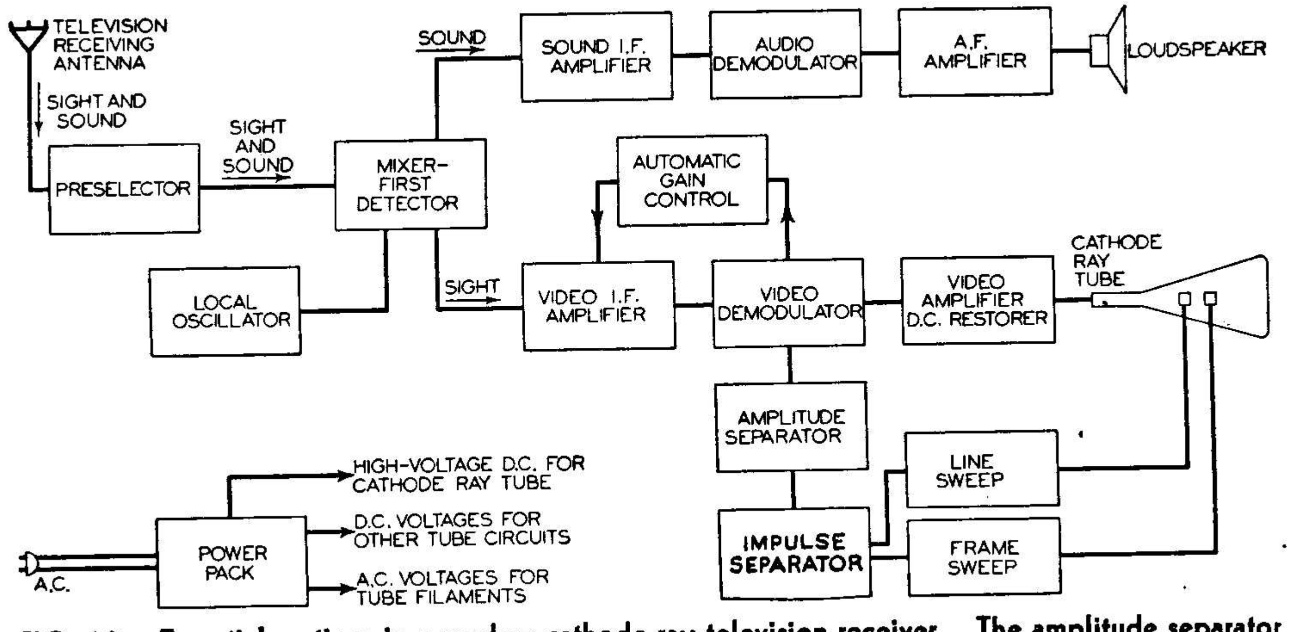
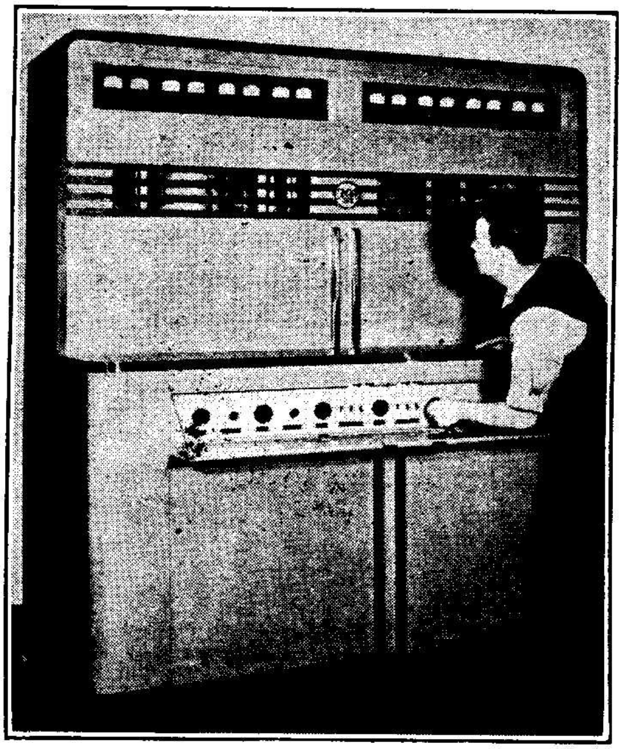


FIG. 16. Essential sections in a modern cathode ray television receiver. The amplitude separator is also known as the clipper, and the impulse separator is often called the frequency separator.

receiver, a.g.c. compensates for fading and also serves to supply the demodulator with an essentially constant signal. Of course, normal fading due to interaction between ground and sky waves does not exist in a television system, but it is perfectly possible for an effect like fading to occur due to swaying of the receiving antenna or the transmission line in the wind, or to reflection of radio waves by a moving automobile in the path between transmitter and receiver. If there are two or more television stations in a given locality, one may provide a stronger signal than the other at a given receiving point, causing different signal levels at the demodulator. Automatic gain control can compensate for all these effects. The circuits associated with or following the video detector are in some cases adjusted according to the amplitude of the television signal; this means that for reliable reception it is important that the video demodulator be fed with a reasonably constant signal. This condition can be met if automatic gain control is provided.



Courtesy RCA Mfg. Co. Inc.

RCA one-kilowatt television transmitter, developed to enable experimental stations to render a satisfactory service over a reasonable area without too great an initial expense for equipment.

In sound receivers, the a.v.c. system is actuated by the average carrier level; in a television system, however, the average carrier level varies with the nature of the video signal being transmitted at any instant. The one fixed characteristic of a television signal is the black level; for a given station this is fixed and corresponds to a definite carrier level. The synchronizing impulses, which are transmitted at amplitudes above the black level, are likewise fixed from instant to instant, so by feeding the television signal from some point in the receiver where the pedestals line up with each other (such as at the output of the video demodulator) and using a filter which makes the output follow the peaks of the impulses, we can secure for the a.g.c. system a d.c. voltage whose value varies with the true carrier level of a television transmitter.

The video demodulator will usually be followed by one or more video-frequency amplifier stages. The exact number of stages used depends upon *the amount of gain required* and *the phase of the television signal* at the input of the video amplifier. Stability becomes another important consideration when a large number of stages is employed and amplification at low video frequencies is essential. Video-frequency amplifiers will invariably be of the resistance-capacitance type, capable of providing uniform amplification for all signals from about 10 cycles up to about 4 megacycles. These amplifiers should really be of the d.c. type, in order to maintain the d.c. characteristic of the television signal, but this is impractical. A d.c. amplifier which will provide the required gain is not only excessively high in cost but also has a tendency

to produce undesirable low-frequency oscillations. A conventional a.c. amplifier with resistance-capacitance coupling is ordinarily used instead; with this, the d.c. component is temporarily removed from the signal, and we amplify an a.c. signal.

Up to the video demodulator stage, the television signal is a modulated carrier having negative modulation, in which the video components of the television signal are negative in voltage with respect to the black level. The television cathode ray tube requires a modulated d.c. signal with a postive picture phase, in which the video components of the signal voltage are positive with respect to the black level.

The television signal can be removed from a diode detector as a d.c. signal with either positive or negative picture phase, as desired. We have this additional fact to keep in mind, that a resistance-capacitance coupled amplifier will reverse the phase of a signal voltage (reverse the picture phase). This means that if we supply to the diode detector a carrier signal having negative modulation, and remove from the detector a positively-modulated d.c. signal (a signal with a positive picture phase), we must use two video amplifier stages in order to secure a positive picture phase for the cathode ray tube. If we remove the television signal from the detector as a negatively modulated d.c. voltage (a signal with a negative picture phase), we must use either one or three video amplifier stages to give the proper phase at the input of the cathode ray tube.

If the video amplifier amplifies only the a.c. component of the television signal, as is usually the case, *a d.c. restoring circuit* should be used just ahead of the television cathode ray tube to restore the d.c. component. This d.c. potential must be restored in such a way that the pedestals will all line up with each other again, for they may be thrown considerably out of line by the video amplifier stages. All of the components in the television signal, including the video signal itself, the horizontal and vertical synchronizing impulses, the equalizing impulses and the pedestals, are applied to the control electrode of the cathode ray tube.

In order to make the electron beam in the cathode ray tube sweep both horizontally and vertically, we need two saw-tooth sweep oscillators; these must be of such a nature that they can be controlled by the horizontal and vertical synchronizing impulses in the television signal. The impulses must be separated from the video signal before they can be applied to these sweep circuits; this is accomplished by the stage known as the *synchronizing separator*, the *amplitude separator*, or the *clipper*. The television signal voltage which is fed into the amplitude separator must be *a modulated d.c. signal voltage with the pedestals lined up.* When this signal is fed into a negatively-biased diode tube or into a triode tube which is negatively biased so that only the impulses can get through, the desired separation of impulses from video signals is secured.

After the impulses have been separated from the video signal, there will remain the problem of separating the horizontal impulses from the vertical impulses. A separate circuit is required for this job; this circuit is called the *impulse separator* or *frequency separator*, and supplies the synchronizing impulses to the line and frame sweep oscillator circuits.

Power packs are an essential part of a television receiver, since the

various tubes used will require both a.c. and d.c. operating voltages.

Adjustments must be provided in the video section of a television receiver for controlling the amplitude separator, the impulse separator, the horizontal and vertical sweep oscillators, and the d.c. restoring circuit; these controls may be of the screw-driver type, however, for once they are set properly, they will remain in adjustment for long periods of time. There is also need for a control which will adjust the beam of the cathode ray tube to the exact center of the screen when no sweep voltages are applied to the horizontal and vertical deflecting plates, for even with modern tube-making machinery it is not possible to align the various electrodes with sufficient accuracy to keep the spot at the exact center of the screen. Centering of the spot is accomplished with simple circuits which introduce adjustable biasing voltages in series with the horizontal and vertical deflecting plates. The size of the picture and the aspect ratio can be varied by changing the magnitudes of the sweep voltages.

Although the controls just described are essential for preliminary adjustment, they are rarely if ever used by the owner of a television receiver. The essential picture controls which require adjustment by the owner include a tuning control (either a manually rotated knob or a push-botton tuning system) for simultaneously tuning in the video and audio signals from the desired station when there are several television stations in a locality, a focus control, a contrast (gain) control for the video amplifier to adjust picture contrast, and a background brilliancy control which adjusts the d.c. bias applied to the control grid of the cathode ray tube and thereby places the pedestals of the television signal at the cut-off point on the grid voltage-brightness characteristic curve of the tube. In addition, the sound section of the receiver will have a volume control and sometimes a tone control. The on-off switch is usually combined with the volume control.

LOOKING FORWARD

In this first introductory Lesson on television, we have surveyed the important needs of a television system. In some cases brief explanations of these needs have been given, and in other cases we have simply made statements because the explanations would be lengthy and not essential to the clearness of this "bird's-eye view" of the entire modern television set-up. The various methods for producing saw-tooth sweep signals, for providing interlocks and for separating impulse signals will all be taken up in later Lessons, along with typical circuits for the various other sections described in this Lesson.

Lesson Questions

Be sure to number your Answer Sheet with the number appearing on the front cover underneath the Lesson title.

Place your Student Number on every Answer Sheet.

Send in your set of answers for this Lesson immediately after you finish them, **as instructed in the Study Schedule.**

1. What is a scene converted into by the process of scanning?

2. If the size of a television image is increased, should you move closer or farther away from the receiver to see a properly blended picture?

3. What three important signals must be transmitted on the picture carrier in an electronic television system?

4. One requirement for double interlaced scanning of a given number of lines per second at a given frame frequency is a vertical scanning rate which is twice the frame frequency. What is the other requirement?

5. What three adjustable controls are required for the sight section of a modern television receiver in addition to the tuning control?

6. In a standard 6-megacycle wide television channel, what is the frequency relationship between the sound carrier and the picture carrier? (State how many megacycles higher or lower the sound carrier is than the picture carrier.)

7. What is meant by negative modulation of the picture carrier signal?

8. Why is each vertical synchronizing impulse divided into six serrations?

9. If the video amplifier in a television receiver amplifies only the a.c. component of the television signal, what circuit should be used just ahead of the television cathode ray tube?

10. What should be the nature of the television signal voltage which is fed into the amplitude separator section of the television receiver?